PROJECT WISH: THE EMERALD CITY

OHIO STATE UNIVERSITY   N91-18146

INTRODUCTION

When Project WISH (Wandering Interplanetary Space Harbor) was initiated as a multi-year project, several design requirements were specified. The space station must have a lifetime of at least 50 years, be autonomous and independent of Earth resources, be capable of traveling throughout the solar system within a maximum flight time of three years, and have a population of 500-1000 people. The purpose for the station is to provide a permanent home for space colonists and to serve as a service station for space missions.

In the process of designing the Emerald City, given the stated design requirements, the following systems were studied: Orbital Mechanics, Propulsion, Vehicle Dynamics and Control, Life Support, Communications, Support Systems, Power, Thermal Control, and Configuration. The travel times and necessary velocity changes to move throughout the solar system were determined in orbital studies. The Propulsion System Study then focused on the necessary impulse and thrust levels to provide the velocity changes derived by the Orbital Mechanics group. Vehicle Dynamics and Control considered the station's flexible dynamics and rigid attitude behavior. This analysis provides information for orbit selection, body shape and configuration, and propulsion requirements for station keeping in a nominal orbit. The Life Support System must satisfy all the physical needs of the inhabitants. It will provide the air, water, waste management, and food requirements for the crew and passengers. The Support Systems are communication, shuttles, and maintenance. The Communication system will provide the colonists with a means of talking to other colonists and sending valuable scientific data to earth. Shuttles will move people and supplies to and from the station. Repair and upkeep of the various systems on the station will be provided by the Maintenance Subsystem. All the electrical power used to run and maintain the station will be supplied by the Power System. The temperature ranges required by the people and equipment will be controlled by the Thermal Control System. Finally, everything is put together and an initial configuration of the station, the Emerald City, is described.

ORBITAL MECHANICS

Orbital mechanics determined whether the Emerald City could travel anywhere throughout the solar system within the mission requirement of three years. Using a trajectory optimization computer program obtained from NASA Lewis Research Center, velocity changes (ΔVs) for many orbital transfers were calculated. Adjusting for gravitational effects by roughly multiplying by a factor of two, the highest mission ΔVs were compared and checked against propulsion feasibilities.

From this, an outer limit was chosen to be the orbit of Saturn. This came from comparing the worst cases of planet to planet transfers. The ΔV from Saturn to Jupiter is about 100 km/sec, and from Uranus to Saturn is about 200 km/sec. The propulsion system cannot reach numbers of 200 km/sec, in general, for the anticipated mass of the ship.

Also, a nominal orbit was selected. A variety of orbital shapes and uses were examined. A circular orbit at 3.2 A.U. was chosen because it put the ship close to both the asteroid belt and Jupiter, so that raw materials for resupply and repair could be reached. It was located on the ecliptic plane to minimize z-directional velocity changes.

The nominal orbit will also serve as a place to do maintenance and to rest between missions. It will also be advantageous for communications, since colonies that need the ship will know its approximate location. There may be other reasons for having a nominal orbit and work continues in finding an optimized place for the ship to stay.

PROPULSION SYSTEM

The propulsion system of the Emerald City was one of the major subsystems that has been studied during the first year of Project WISH. It should also be one of the key areas of development in the project because, without an effective propulsion scheme, the Emerald City will be unable to accomplish its mission of supporting colonies on distant worlds and gathering data from previously inaccessible sources.

The propulsion system study for the Emerald City was divided into five phases. In the first phase, the mission requirements of Project WISH were broken down and studied in order to determine their effect on propulsion. Two influences on the selection of a propulsion unit were the three-year flight time and the mass of the station. These will determine the specific impulse that must be generated to accomplish the missions.

In the second phase, equations were developed that could relate how much of an effect the demands of the mission would have on the propulsion system. Equations relating the payload mass ratio, propellant mass ratio, and impulse to important design criteria such as the specific impulse and specific power were then used to compare the capabilities of different propulsion systems for given missions.

The third phase consisted of system comparisons for four propulsion concepts: chemical, electrical, nuclear, and antimatter. Only nuclear and antimatter were found to offer the combination of high thrust and high specific impulse that would be required for Project WISH.

In the fourth phase, an in-depth study of the two promising systems was performed. From this investigation, antimatter propulsion was chosen because of its higher thrust and specific impulse potential. Even though the nuclear systems are far more developed than antimatter, the thrust and specific impulse were simply too low for the more demanding missions.

The fifth phase was to carry out mission analysis using concepts specific to antimatter propulsion. One of the most important concepts is the mass ratio (initial to final mass) that will result in the minimum use of antimatter. This ratio was found to be 5:1 and has been used to determine the impulse and antimatter mass required for the mission of Project WISH.

VEHICLE DYNAMICS AND CONTROL

A system the size of the Emerald City is structurally too complex to be considered rigid. Therefore, some analysis of the flexibility effects was warranted. An initial longitudinal dynamic model was developed in order to perform parameter studies to determine crew station location and acceleration levels. Relationships among the structural parameters, propulsion system parameters, mass ratios, and propulsion time were established. Some model analysis is presented and some simulation is discussed.

A three dimensional lumped-mass model of the crew compartment was introduced in order to further study its in-plane and out-of-plane flexible dynamics. Out of these systems, some design constraints will be imposed. This study is in its infancy but is very important to the overall design.

Attitude dynamics covered analysis of the Emerald City as an uncontrolled, rotating, rigid body representing a gyroscopic system. By obtaining the configurations at which the space station may be stable, minimum control power will be used to maintain attitude stability. After determining the positions of equilibrium for a generic spinning body in a heliocentric orbit, a control system study is done in order to analyze the body disturbed from equilibrium.

By studying the nonlinear equations of motion, it is shown that the stability of the Emerald City is dependent on body shape, rate of spin, and orbital radius. These parameters translate into astronautical terms as structural configuration, artificial gravity, and parking orbit. Equilibrium analysis identified a unique orientation relative to the orbit plane for the Emerald City to insure non-diverging attitude.

The Emerald City, a spinning body in its steady-state configuration was then studied for control of small perturbations from its equilibrium conditions. The control system study used a linear quadratic regulator solution to estimate the amount of control power that might be needed for a number of configurations and artificial-g spin rates.

LIFE SUPPORT SYSTEM

The Environmental Control and Life Support System (ECLSS) for the Emerald City will be a nearly closed loop system. All life requirements will be met by the six integrated subsystems: Air Revitalization (ARS), Atmosphere Control (ACS), Temper-

ature and Humidity Control (THCS), Water Waste Management (WWMS), Solid Waste Management (SWMS), and Nutritional Supply (NSS).

The ARS is responsible for carbon dioxide reduction, oxygen generation, and air composition regulation. The ACS will circulate air and filter out or absorb any dust particles or harmful chemicals. THCS will remove humidity during the oxygen regeneration process and through the use of water separators. All equipment within the station will be maintained at proper working temperatures through the use of a water-based transport media heat rejection system. Due to the large volume of water used in the station per day, a WWMS must have an efficiency of recovery in excess of 99%. The WWMS for this ECLSS will use a thermopervaporation process that can achieve this efficiency. The SWMS is responsible for retrieving all reusable resources from both plant and human waste. The NSS will provide all the food requirements for the crew through the use of a hydroponics system.

COMMUNICATION SYSTEM

For the Project WISH scenario, a communication system capable of extremely high data rate and long range capability was required. To meet these design parameters, both microwave systems and laser systems were examined. Due to the substantial advantages in available bandwidth and diffraction limits, the laser system was chosen over the microwave system.

The smallest laser beam width that can be produced for use in communications is one microradian. From this, the transmitter antenna size was determined by performing a simple calculation involving wavelength.

For complete laser communication system characteristics, the range equation was used. This equation relates the range, transmitter power, antenna diameters, noise, and receiver power. Sample calculations for an optimal communication system showed that a 500 kW laser transmitter could easily send 12500 Mbits/sec of digital data across 12 A.U. of empty space using a 61-cm transmitter. The receiver antenna would require a diameter of at least 71.6 cm.

Problems with the communication system centered around having direct line of sight to the receiver and concern about the accuracy of assuming an "optimal" system. The first problem can be solved by incorporating relay stations in the form of satellites or planetary colonies. The second problem can be alleviated by reserving extra electric power for the system should factors such as modulation techniques, noise considerations, and beam capture prove to be more degrading to system performance than assumed in the optimal system.

POWER SYSTEM

A power budget was required to design a system that can produce the needed amount of electrical power. From the subsystems, the following preliminary budget estimates were obtained.

Estimated Power Budget:

1.	Propulsion (storage)	several	GWe
2.	Life Support	3	MWe
3.	Communications	10	MWe
4.	Dynamics and Control	several	GWe
5.	Heat Transfer	0.6	GWe
6.	Shuttle and Maint.	5	MWe
7.	Misc. Power	5	MWe

The parameters of fission and fusion reactors were reviewed to identify a power system that would provide the electrical power required by the Emerald City. Based on mass, specific power, and stability, the power source for the Emerald City will be a rotating particle bed reactor. However, if the power budget does increase to the tera-watt range, a fusion reactor would then be needed since these reactors have the potential of supplying an essentially inexhaustible source of energy. In this case, the considerations of mass and specific power will not be important compared to total power achieved.

THERMAL SYSTEM

The thermal control system of the Emerald City will use active and passive systems to control the temperature of the station. An active thermal control system employs radiators or a mass conversion system to dissipate waste thermal energy. On the other hand, a passive thermal control system uses paints, coatings, and insulations to control the station temperatures.

The Emerald City will use a radiator to control most of the waste heat produced by the power system and other subsystems. A radiator, similar to the Rotating Bubble Membrane Radiator (RBMR), was chosen. It differs from a RBMR in that it wraps around the cylinder of the station forming a torus rather than a sphere. The radiator will use nozzles to spray molten metal on a surrounding envelope or bubble. As the droplets hit the envelope, they radiate thermal energy. Since the bubble will be attached to the spinning section of the station, the centrifugal force will move the droplets to a trough where they are collected and recirculated.

This type of radiator was chosen over other types because of mass and meteoroid protection. The tiny droplets of fluid and the bubble will provide the needed surface area to dissipate the waste heat. Because the droplets are so tiny, they have very low mass and the mass of the total system is much lower compared to conventional heat pipes. In addition, meteoroid protection is provided by the bubble. If a meteoroid hits the radiator, it passes through the bubble and continues on its course. However, the bubble is made of a self-sealing material, so that any rips or tears repair themselves and there is little loss of the circulating fluid. This type of meteoroid protection provides additional mass savings because armoring, typical in convention systems, is not needed.

CONFIGURATION

To determine a feasible configuration, all of the subsystems had to be accommodated. Not only does each of the subsystems have to be in an appropriate place with respect to the others, but the entire unit has to meet the stability and control requirements. At this stage in development, the requirements are very general. This configuration is a place to start rather than a final design.

The systems that need to be integrated are the shuttle, communications, habitat, power, thermal control, and propulsion. These systems must be pieced together so that the stability requirements are met and construction is feasible.

The habitat must protect the crew from the hazards of space. These hazards include micrometeors, solar and cosmic radiation, and near-vacuum conditions. Besides being a protective shelter, the habitat must also accommodate agriculture and life support systems in an architecture that will avoid unnecessary stresses for its human occupants.

The propulsion system must be able to access the large amounts of hydrogen it will use as a working gas. The drive will emit large amounts of gamma rays, which are lethal to living organisms without shielding.

The design will be composed of various section roughly correlating to the subsystems. These sections include the habitat, power and propulsion, fuel tankage, radiator, de-spun platform, and the connecting pieces. This configuration is pictured in Fig. 1.

At this point in the project, the habitat is conceived as a torus with an outside diameter of 600 m and a tubular radius of 60 m to provide 0.8 g at a spin rate of 1.6 rpm. However, larger torus diameters such as 1850 m with 1-g at 1 rpm may have to be considered when all subsystem designs are to be integrated optimally for the overall system. If this structure is made of a medium grade aluminum alloy, then the minimum thickness of the shell will correspond to radiation shielding of 3000 kg/m^2, just over the 2800 kg/m^2 required for galactic radiation protection. Certainly, psychological considerations
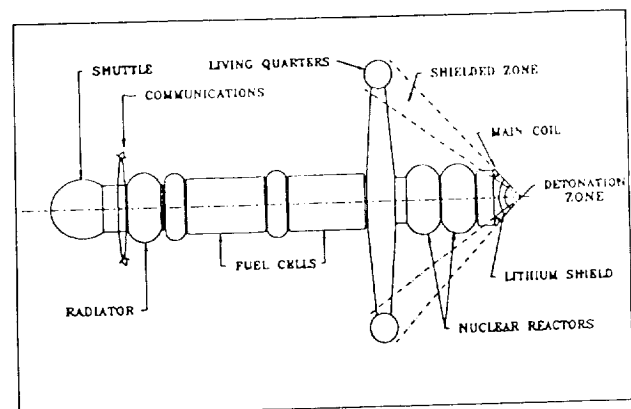

Fig. 1. Configuration

will play a large role in designing the interior architecture of the torus.

The propulsion system is placed on one end to transfer all of the thrust force through the axis of the spacecraft. Each set of fuel tanks will be connected to a main, load-carrying structure. Each fuel section will also have plumbing for the fuel, power transmission, heat pipes, and communication capabilities.

On the very end will be the radiator and the de-spun section containing the shuttle and the communications platform. The connections between the de-spun and spun sections are mechanical, power, fuel, and personnel transport. The connections are not complex and can be produced reliably.

The main support structure that runs through the fuel cells will connect directly to the radiator. This structure will also run through the nuclear reactor and connect to the propulsion system. Although the structure could be made out of any strong material, it may be advantageous to make it out of reinforced concrete. This material has a very large compressive strength to weight ratio.

The torus will be connected to the main structure with a large number of spokes, similar to a bicycle wheel. There will also be two pressurized tubes connecting the habitat with similar tubes in the main structure. These tubes will be the means of transportation between the habitat and the shuttles.

CONCLUSION

Hard work in researching and performing parametric studies to make the Emerald City of Project WISH realizable has taken place by starting from scratch and creating a sketch of a possible design for the space oasis. With such an undertaking, the more that is learned merely reveals how much more needs to be learned. Since Project WISH began, an initial decision on propulsion and power systems has been made, parameters for life support systems have been established, various subsystems have been analyzed, and necessary orbital restrictions have been determined. An initial configuration has been produced and work on detailed subsystem studies has begun. Project WISH will continue over the next two years, refining studies begun this year and incorporating additional aspects not yet considered.